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(54) Method for controlling an exhaust gas temperature of an engine

(57) A method of controlling an exhaust gas temperature of an internal combustion engine 12 during low engine speeds and low engine load conditions is provided. The method includes the step 68 of calculating a target engine operational parameter responsive to an air/fuel ratio of the engine 12 and an engine speed error. The target engine operational parameter is one the following parameters: a target intake manifold pressure, a target intake manifold mass air flow, or a target air/fuel ratio. The method further includes the step 98 of calculating a commanded position for a throttle valve 18 disposed in an intake manifold 16 of the engine 12. The commanded position is calculated responsive to the target engine operational parameter and a measured engine operational parameter. The measured engine operational parameter is one of the following parameters: a measured intake manifold pressure, a measured intake manifold mass air flow, or a measured air/fuel ratio. The method further includes the step 138 of controlling the throttle valve 18 responsive to the commanded position to control the exhaust gas temperature of the engine 12. The method further includes the step 140 of setting a commanded engine speed to a predetermined speed to further control the exhaust gas temperature. Finally, the method includes the step 142 of injecting a predetermined amount of fuel into one of the cylinders 44 of the engine 12 late in a power stroke of the one or more cylinders 44 to further control the exhaust gas temperature.

EP 1 146 216 A2

Description

[0001] This invention relates to a method for controlling an exhaust gas temperature of an internal combustion engine. In particular, the method relates to controlling the exhaust gas temperature to allow regeneration of an exhaust filter during low engine speeds or low engine load conditions.

[0002] Emission after treatment devices are utilised to collect particulate matter from the exhaust gas of an internal combustion engine. In particular, conventional emission after treatment devices for diesel engines include particulate filters, oxidation catalysts, and nitrous oxide (NOx) catalysts. A problem associated with particulate filters is that the particulates, which consist largely of carbon particles, tend to plug the filters resulting in a restriction to the exhaust gas flow. A conventional method of regenerating/cleaning the filter involves increasing the exhaust gas temperature above a predetermined temperature (e.g., above 450°C) to incinerate the carbon particles in the filter.

[0003] Conventional methods have increased the exhaust gas temperature of an engine by controlling a throttle valve in an intake manifold of the engine. In particular, it is known that by throttling/closing the throttle valve, the exhaust gas temperature may be increased. Further, numerous methodologies have been utilised for controlling the throttle valve. In one conventional method, the intake throttle valve is controlled utilising the difference between a calculated target intake manifold pressure and an actual intake manifold pressure. The target intake manifold pressure is calculated using an engine speed and an engine load. This conventional method has a drawback of being unable to regenerate the particulate filter during low engine speeds or low engine load conditions because the required amount of throttling would result in unstable engine operation. Accordingly, when the engine is operating during low engine speeds or low engine load conditions, the particulate filter may become clogged creating an undesirable restriction in the exhaust gas flow and allowing increased exhaust gas emissions.

[0004] There is thus a need for a method of controlling an exhaust gas temperature of an engine during low engine speeds and/or low engine load conditions to initiate the regeneration of a particulate filter or the like.

[0005] A method embodying the present invention for controlling an engine exhaust temperature is utilised in an engine having cylinders, an intake manifold, and a throttle valve disposed within the intake manifold. The method includes the steps of calculating a target engine operational parameter responsive to an air/fuel ratio of the engine and an engine speed error of the engine. The target operational parameter may comprise one of the following parameters: a target intake manifold pressure, a target intake manifold mass air flow, or a target air/fuel ratio. The method further includes the step of calculating a commanded position for the throttle valve responsive to the target engine operational parameter and a measured engine operational parameter. The measured engine operational parameter may comprise one of the following parameters: a measured intake manifold pressure, a measured intake manifold mass air flow, or a measured air/fuel ratio. The method further include the step of controlling the throttle valve responsive to the commanded position to control the exhaust gas temperature. The method further includes the step of setting a commanded engine speed to a predetermined speed to further control the exhaust gas temperature. Finally, the method may include the step of injecting a predetermined amount of fuel into one of the cylinders of the engine late in a power stroke of the cylinder to further control the exhaust gas temperature.

[0006] A method for controlling the exhaust gas temperature of an engine in accordance with the present invention represents a significant improvement over conventional methods. In particular, the inventive method allows for the regeneration of particulate filters during low engine speeds conditions (e.g., an engine speed less than 1000 RPM) and/or low engine load conditions. As a result, the inventive method allows particulate filters to operate more effectively when the engine is idling or is being operated at relatively low speeds.

[0007] The invention will now be described further, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a combination schematic and block diagram of an engine and a control system for carrying out a method in accordance with the present invention;

Figures 2A-G are flow charts illustrating a method for controlling an exhaust gas temperature of an engine in accordance with the present invention; and

Figures 3A-F are diagrams illustrating engine parameters in accordance with a method for controlling an exhaust gas temperature of an engine in accordance with the present invention.

[0008] Referring now to the drawings wherein like reference numerals are used to identify identical components in the various views, Figure 1 illustrates an automotive vehicle generally indicated by numeral 10. The vehicle 10 includes an internal combustion engine 12 and a microcontroller 14.

[0009] The engine 12 may comprise an internal combustion engine such as a diesel engine. The engine 12 may include an intake manifold 16, a throttle valve 18, a throttle valve actuator 20, a fuel injector 21, an exhaust manifold 22, a filter assembly 24, a turbocharger 26, an EGR valve 28, a mass air flow sensor 30, a throttle valve position sensor 32, a pressure sensor 34, a speed sensor 36, an air/fuel sensor 38, and pressure sensors 40, 42.

[0010] The intake manifold 16 receives compressed air from the turbocharger 26 and directs the air flow to

cylinders 44 of the engine 12. The configuration of the manifold 16 may vary based upon the number of cylinders 44. The manifold 16 includes the throttle valve 18 disposed therein.

[0011] The throttle valve 18 is provided to selectively restrict the amount of air flowing through the manifold 16 to thereby control the operation of the engine 12, and in particular to control the exhaust gas temperature of the engine 12. When the valve 18 is throttled (e.g., moved from a full-open position to a partially closed position), the exhaust gas temperature increases. The position of the valve 18 may be controlled to increase the exhaust gas temperature above a predetermined temperature (e.g., above 450 C), to regenerate the filter assembly 24. The method for controlling the valve 18 to increase the exhaust gas temperature will be discussed in more detail hereinbelow. The valve 18 is conventional in the art and may comprise a conventional valve capable of restricting the air flow through the manifold 16. For example, the valve 18 may comprise a butterfly valve or the like.

[0012] The throttle valve actuator 20 is provided to move the valve 18 to a specified position. The actuator 20 is conventional in the art and may comprise a pneumatically controlled actuator or a stepper motor actuator or the like. The actuator 20 may respond to electrical signals generated by the microcontroller 14 to adjust the position of the valve 18, thereby varying the flow of air through the manifold 16.

[0013] The fuel injector 21 provides fuel to one of cylinders 44 and is conventional in the art. Although a single fuel injector 21 is illustrated for the purpose of clarity, it should be understood that each of cylinders 44 has a corresponding fuel injector 21. The fuel injector 21 receives fuel from a fuel pump (not shown) and injects a first predetermined amount of fuel into one of cylinders 44 during a power stroke of the respective cylinder 44. Further, the fuel injector 21 may be utilised to inject a second predetermined amount of fuel into one of the cylinders 44 late in the power stroke (i.e., post-injection of fuel) of the respective cylinder 44 to further control the exhaust gas temperature as described in further detail hereinbelow. In particular, the microcontroller 14 may generate control signals that cause the fuel injector 21 to inject the first and second predetermined amounts of fuel, respectively, into one of the cylinders 44.

[0014] The exhaust manifold 22 directs exhaust gas from the cylinders 44 through the turbocharger 26 to the filter assembly 24. The configuration of manifold 22 may vary based upon the number of cylinders 44 of the engine 12.

[0015] The filter assembly 24 is provided to lower the exhaust gas emissions/particulates before the exhaust gas is expelled from the engine 12. The assembly 24 may include an oxidation catalyst 46 and a particulate filter 48.

[0016] The oxidation catalyst 46 is utilised to increase the exhaust gas temperature of the engine 12 prior to the exhaust gas entering the particular filter 48. In particular, the post-injection of fuel into one or more cylinders 44 results in unburned hydrocarbons being expelled from the cylinders 44 into the oxidation catalyst 46. The oxidation of the hydrocarbons in the catalyst 46 is an exothermic reaction resulting in an additional increase in the exhaust gas temperature. Accordingly, the temperature of the exhaust gas exiting the oxidation catalyst may be substantially higher (e.g., up to 200°C higher) than the exhaust gas entering the filter assembly 24. The exhaust gas within the oxidation catalyst is preferably heated to at least 450°C before being expelled into the filter 48---which regenerates the filter 48.

[0017] The particulate filter 48 is provided to capture particulate matter such as carbon particles in the exhaust gas. The filter 48 may be conventional in the art and may comprise a steel-wool filter, a ceramic-monolith filter, or a ceramic-coil filter or the like. As discussed above, the filter 48 must be regenerated/cleaned at certain intervals since the filter 48 may become clogged with carbon particles from the exhaust gas. Further, the filter 48 may be regenerated by throttling the valve 18 and/or post-injecting fuel into the cylinders 44 to thereby increase the exhaust gas temperature above a predetermined incineration temperature (i.e., 450°C) of the carbon particles.

[0018] The turbocharger 26 may be provided to compress the air inducted into the engine 12. The turbocharger 26 may include a compressor 50 connected to the intake manifold 16 and a turbine 52 disposed between the exhaust manifold 22 and the filter assembly 24.

[0019] The EGR valve 28 is provided to reduce NOx emissions from the engine 12. The valve 28 is conventional in the art and is disposed between the intake manifold 16 and the exhaust manifold 22.

[0020] The mass air flow sensor 30 generates a signal V_A indicative of the mass air flow in the intake manifold 16. The microcontroller 14 may receive the signal V_A and derive the measured value of mass air flow MAF from the signal V_A. The sensor 30 is conventional in the art and may be disposed in an inlet 54 upstream of the intake manifold 16.

[0021] The throttle valve sensor 32 generates a signal V_V indicative of the position of the valve 18 and is conventional in the art. The microcontroller 14 may receive the signal V_V and derive the measured position THR_M of the valve 18 from the signal V_V. In a constructed embodiment, the measured position THR_M of the valve 18 may have a range from 0-1 wherein the value 0 represents a full-open position (i.e., no throttling) of the valve 18 and the value 1 represents a full-closed position of the valve 18. It should be understood, however, that the position of the valve 18 may represented in a plurality of alternate ways. For example, the position of the valve 18 can be represented by a percentage of the full-open or full-closed position or by a rotation angle associated with the valve 18.

[0022] The pressure sensor 34 generates a signal V_{P1} indicative of the pressure within the intake manifold 16. The microcontroller 14 receives the signal V_{P1} and derive the measured value of the intake manifold pressure P from the signal V_{P1}. The pressure sensor 34 is conventional in the art.

[0023] The speed sensor 36 generates a signal V_N indicative of the speed of a crankshaft of the engine 12. The microcontroller 14 receives signal V_N and derives the measured value of the engine speed N from the signal V_N. The speed sensor 36 is conventional in the art.

[0024] The air/fuel ratio sensor 38 generates a signal V_{AF} indicative of the air/fuel ratio of the engine 12. The microcontroller 14 receives the signal V_{AF} and derives the measured value of the air/fuel ratio AF from the signal V_{AF}. The sensor 38 is conventional in the art and is disposed between the turbine 52 and the filter assembly 24.

[0025] The temperature sensor 39 generates a signal V_T, indicative of the temperature at the inlet of the filter assembly 24. The microcontroller 14 receives the signal V_T and derives the measured value of the exhaust gas temperature T of the exhaust gas entering the filter assembly 24 from the signal V_T.

[0026] The pressure sensors 40, 42 generate signals V_{P2} V_{P3} respectively indicative of the pressures at the inlet and outlet respectively, of the filter assembly 24. The microcontroller 14 receives signals $V_{P2,}$ V_{P3} and derives the measured values of the inlet and outlet pressures P_I P_C from the signals $V_{P2,}$ $V_{P3,}$ respectively. Alternately the pressure sensors 40, 42 may be replaced by a single differential pressure sensor (not shown) that generates a signal indicative of the pressure drop across the filter assembly 24. The microcontroller 14 may determine whether a regeneration of filter 48 is required based upon the difference between the inlet and outlet pressures P_I P_O.

[0027] The microcontroller 14 is provided to control the engine 12 and in particular to control the throttle valve 18. The microcontroller 14 is conventional in the art and is electrically connected to the throttle valve actuator 20. the fuel injector 21, the mass air flow sensor 30, the throttle valve position sensor 32, the pressure sensor 34. the speed sensor 36, the air/fuel ratio sensor 38, the temperature sensor 39, and the pressure sensors 40. 42 The microcontroller 14 includes a read-only memory (ROM) (not shown) that stores a software program for implementing the method in accordance with the present invention.

[0028] A general overview of the method of controlling the exhaust gas temperature of an engine by controlling the throttle valve 18 will be described before proceeding with a detailed description of the entire inventive method.

[0029] A target engine operational parameter TP is calculated responsive to the engine speed error N_{ERR} and the air/fuel ratio AF. The parameter TP is set to a value that ensures that the control of the engine speed and the air/fuel ratio always receive priority over control of the engine exhaust temperature to prevent stalling of the engine 12 or excessive particulate production due to overfueling the engine 12. The parameter TP may comprise: (i) a target intake manifold pressure, (ii) a target intake manifold mass air flow, or (iii) a target air/fuel ratio. The parameter TP is calculated by adding a target reference offset TO to a base engine operational parameter BP.

[0030] The target reference offset TO is calculated responsive to the engine speed error N_{ERR} and the air/fuel ratio AF. The target reference offset TO may comprise: (i) a target intake manifold pressure offset, (ii) a target intake manifold mass air flow offset, or (iii) a target air/fuel ratio offset. If the engine speed error N_{ERR} is a negative number (i.e., engine speed N is less than commanded engine speed N_C), the target reference offset TO is increased by a calculated amount. Similarly, if the air/fuel ratio AF is less than a minimum air/fuel ratio AF_{MIN}(necessary for proper engine combustion), the target reference offset TO is increased by a calculated amount. Alternately, if the error N_{ERR} is a positive number, the target reference offset TO is not changed. Similarly, if the air/fuel ratio AF is greater than the minimum air/fuel ratio AF_{MIN}, the offset TO is not changed.

[0031] The base engine operational parameter BP may comprise a base (minimum) threshold value for allowing combustion stability within the engine 12 while also providing for relatively high exhaust gas temperatures. The parameter BP may comprise: (i) a base intake manifold pressure, (ii) a base intake manifold mass air flow, or (iii) a base air/fuel ratio. The parameter BP may be derived from the engine speed N and the engine load (determined indirectly by the accelerator pedal position) by reference to a table in the ROM (not shown) of the microcontroller 14 containing a set of values of the parameter BP which vary as a function of the engine speed N and the engine load. Further, the values for the parameter BP are readily determined during initial engine testing of the engine 12 by those skilled in the art. In particular, the value for the parameter BP is determined such that at a measured engine speed and a measured engine load, a required exhaust gas temperature is reached in the engine 12. It should be understood that the parameter BP will be added to a target reference offset TO with identical measurement units to obtain the target engine operational parameter TP. For example, a parameter BP--corresponding to a base intake manifold pressure may be added to an offset TO--corresponding to a target intake manifold pressure offset to obtain a parameter TP--corresponding to a target intake manifold pressure.

[0032] An engine operational parameter error P_{ERR} is utilised to calculate a commanded position THR_{CMD} of the throttle valve 18. The error P_{ERR} is calculated by subtracting the target engine operational parameter TP from a measured engine operational parameter MP. The parameter MP may comprise: (i) a measured intake

manifold pressure P, (ii) a measured intake manifold mass air flow MAF, or (iii) a measured air/fuel ratio AF. Accordingly, the error P_{ERR} may comprise: (i) an intake manifold pressure error, (ii) an intake manifold mass air flow error, or (iii) an air/fuel ratio error. It should be understood that the parameter TP will be subtracted from a parameter MP with identical measurement units to obtain the error P_{ERR}. For example, the parameter TP--corresponding to a target intake manifold pressure--may be subtracted from the parameter MP--corresponding to the measured intake manifold pressure P--to obtain an intake manifold pressure error.

[0033] The commanded position THR_{CMD} is calculated responsive to the target engine operational parameter TP and the measured engine operation parameter MP. More specifically, the commanded position THR_{CMD} is calculated responsive to engine operational parameter error P_{ERR} (P_{ERR} = MP - TP). An error P_{ERR} that is a negative value indicates that the throttle valve 18 is over throttled and therefore the commanded position THR_{CMD} should be set to a value that opens the valve 18 further (i.e., THR_{CMD} should be decreased towards the value O). For example, if the error P_{ERR} represents an intake manifold pressure error that has a negative value (i.e., measured intake manifold pressure P less than target intake manifold pressure), the inventive method will set the commanded position THR_{CMD} to a value that opens the valve 18 further---which increases the measured intake manifold pressure P towards the target intake manifold pressure as desired. Alternately, an error P_{ERR} that is a positive value indicates that the throttle valve 18 is under throttled and therefore THR_{CMD} should be set to a value that closes valve 18 further (i.e., THR_{CMD} should be increased towards the value 1). For example, if the error P_{ERR} represents an intake manifold pressure error that has a positive value (i.e., measured intake manifold pressure P greater than target intake manifold pressure), the inventive method will set the commanded position THR_{CMD} to a value that closes the valve 18 further---which decreases the measured intake manifold pressure P towards the target intake manifold pressure as desired.

[0034] The microcontroller 14 operates in accordance with a software program stored in the ROM (not shown) which implements the method of controlling an exhaust gas temperature in accordance with the present invention. Figures 2A-G form a flowchart of the inventive method that is implemented by the software program.

[0035] Referring to Figures 2A-G, a method of controlling an exhaust gas temperature of an engine in accordance with the present invention will be described. Referring to Figure 2A, the method may include a step 56 that determines if the speed control flag N_{FLAG} is equal to a true condition or a false condition. The microcontroller 14 sets the speed control flag N_{FLAG} to a true condition only if the engine 12 is in the idling condition (accelerator pedal position equal to zero) or during a cruise control condition of the engine 12. If the speed control flag N_{FLAG} is equal to a true condition, the method may advance to a step 58. If the speed control N_{FLAG} is equal to a false condition, the method may advance to a step 60.

[0036] The method may further include the step 58 that calculates the engine speed error N_{ERR} responsive to the measured engine speed N and a commanded engine speed N_C. The engine speed error N_{ERR} may be obtained using the following formula:

$$N_{ERR} = N - N_C.$$

[0037] The method may further include the step 62 following the step 58 that calculates a fuelling level W responsive to the engine speed error N_{ERR}. The fuelling level W may be calculated using the following two formulas:

$$X = X + (\Delta T * N_{ERR}); \text{ and } W = (Ka * N_{ERR}) + (Kb * X);$$

where

X = an integrated value of N_{ERR}
ΔT = sampling time of the method
Ka = a proportional gain
Kb = an integration gain

[0038] The method may further include a step 64 following the step 62 that calculates an air/fuel ratio AF responsive to the fuelling level W of the engine 12 and the mass air flow MAF in the intake manifold 16. The air/fuel ratio AF may be calculated using the following formula: AF = MAF / W. In an alternate embodiment, the air/fuel ratio AF may be calculated as disclosed in commonly owned U.S. patent application 09/236,991, filed on January 26, 1999, and incorporated herein by reference in its entirety. In yet another alternate embodiment, the step 64 may measure the air/fuel ratio AF using the air/fuel ratio sensor 38 instead of calculating the air/fuel ratio AF.

[0039] In the step 60, if the speed control flag N_{FLAG} is equal to a false condition (indicating that engine 12 is not in idle mode or cruise control mode), the fuelling level W is calculated responsive to a measured accelerator pedal position and the engine speed N. After the step 60, the method advances to a step 64.

[0040] The method may further include a step 66 after the step 64 that determines if the regeneration flag R_{FLAG} is set to a true condition or a false condition. The microcontroller 14 sets the regeneration flag R_{FLAG} to a true condition if the microcontroller 14 has determined that the filter 48 needs to be regenerated. Several methodologies may be utilised to determine when to initiate regeneration of the filter 48. For example, a pressure difference Δ between the inlet and outlet pressures P_I, P_O, of filter assembly 24, may be used to determine when to initiate regeneration. It is well known that when

the filter 48 becomes clogged with carbon particles, the pressure difference ΔP increases. Accordingly, if the pressure difference ΔP is greater than a predetermined pressure difference, the microcontroller 14 may set the regeneration flag R_{FLAG} to the true condition. If the regeneration flag R_{FLAG} is equal to the true condition, the method may advance to a step 68. If the regeneration flag R_{FLAG} is equal to the false condition, the method may advance to the step 56.

[0041] The method may further include the step 68 following the step 66 that calculates the target engine operational parameter TP responsive to the air/fuel ratio AF and the engine speed error N_{ERR}.

[0042] Referring to Figure 2B, the step 68 may include the substeps 70, 72, 74, 76, 78, and 80. In the substep 70, the microcontroller 14 determines if the speed control flag N_{FLAG} is equal to a true condition. If the flag N_{FLAG} is equal to a true condition (idle mode or cruise control mode), the method may advance to the substep 72. If the flag N_{FLAG} is equal to a false condition, the method may advance to the substep 74.

[0043] In the substep 72, a first target offset TO_1 is calculated responsive to the engine speed error N_{ERR}. Referring to Figure 2C, the substep 72 may include the substeps 82, 84, 86, 87, 88, 89, and 90. In the substep 82, the microcontroller 14 determines if the engine speed error N_{ERR} has a negative value which corresponds to the engine 12 operating at a speed N less than the commanded engine speed N_C. If the engine speed error N_{ERR} has a negative value, the engine speed error N_{ERR} is multiplied by a value C_1 ($C_1 > 1$) to obtain a value N_{ERRO} in step 84. The value C_1 is utilised to increase an engine speed error N_{ERR} having a negative value (corresponding to a over throttling condition of valve 18). If the engine speed error N_{ERR} has a positive value, the value N_{ERRO} is set equal to zero in the step 86. In the step 87, a value Y is calculated using the following formula:

$$Y = Y + (\Delta T * ((Kg * N_{ERRO}) - 1));$$

where

Y = an integrated value proportional to N_{ERR}
Kg = a proportional gain wherein $Kg < 0$
ΔT = sampling time of the method

[0044] The step 88 determines if the value of the integrated value Y is less than zero. If the value Y is less than zero, the value Y is set equal to zero in the step 89. Accordingly, the lower limit of the value Y is equal to zero. In the step 90, the first target offset TO_1 is calculated using the following calculation: $TO_1 = N_{ERRO} + Y$.

[0045] Referring to Figure 2B, the substep 74 sets the first target offset TO_1 equal to zero if the speed control flag N_{FLAG} is equal to a false condition in the substep 70.

[0046] The substep 76 calculates a second target offset TO_2 responsive to the air/fuel ratio AF. Referring to Figure 2D, the substep 76 may include the substeps 92, 94, and 96. In the substep 92, the air/fuel ratio AF is compared to a minimum air/fuel ratio AF_{MIN} necessary for proper engine combustion. If the air/fuel ratio AF is less than the minimum air/fuel ratio AF_{MIN}, the second target offset TO_2 is calculated in the substep 94 using the following equation: $TO_2 = (AF_{MIN} - AF) * C_2$; where $C_2 > 1$. If the air/fuel ratio AF is greater than or equal to the minimum air/fuel ratio AF_{MIN}, the second target offset TO_2 is set equal to zero in the step 96.

[0047] Referring to Figure 2B, the substep 78 following the substep 76 adds the first target offset TO_1 to the second target offset TO_2 to obtain a target reference offset TO.

[0048] The substep 80 after the substep 78 adds the target reference offset TO to a predetermined base engine operational parameter BP to obtain a target engine operational parameter TP. As discussed above, the parameter BP may comprise a base (minimum) threshold value that will still allow combustion stability within the engine 12 and allow for relatively high engine exhaust temperatures. Further, the parameter BP is readily determined through engine testing by those skilled in the art.

[0049] Referring to Figure 2A, the method may further include a step 98 that calculates a commanded position THR_{CMD} for the throttle valve 18 responsive to the target engine operational parameter TP and a measured engine operational parameter MP. Referring to Figure 2E, the substep 98 may include the substeps 100, 102, 104, and 106. In the substep 100, the target engine operational parameter TP is subtracted from the measured engine operational parameter MP to obtain an engine operational parameter error P_{ERR}.

[0050] In the substep 102, a first target position THR_1 is calculated responsive to the engine operational parameter error P_{ERR} and a measured position THR_M of the throttle valve 18. Referring to Figure 2F, the substep 102 may comprise the substeps 108, 110, 112, 114, and 116.

[0051] In the substep 108 the engine operational parameter error P_{ERR} is checked to determine if the error P_{ERR} is a negative value--indicating that the measured engine operational parameter MP is less than the target engine operational parameter TP. If the error P_{ERR} is a negative value, the substep 110 multiplies error P_{ERR} by a value C_2 where $C_2 > 1$. In the substep 112, the value P_{ERRO} is calculated using the following equation: $P_{ERRO} = 0.01 * (1 - THR_M)^2 * P_{ERR}$. The numeral "1" in the foregoing equation represents the full-closed position of the valve 18. It should be understood, however, if the measured throttle position THR_M is expressed in a percentage (i.e., 0-100%) of throttling or other units, the numeral "1" would be modified accordingly to represent the full-closed position. The scaling factor $(1 - THR_M)^2$ is used to compensate for the non-linear characteristics between the measured position THR_M of the throttle valve

18 and the target engine operational parameter TP---to prevent over throttling the valve 18. For example, if the parameter TP corresponds to a target intake manifold pressure and the valve 18 is in the full-open position ($THR_M = 0$), a relatively small change in the commanded position THR_{CMD} of the valve 18 will have a minimal effect on the measured intake manifold pressure--because the air flow through the manifold 16 is still unrestricted. However, when the valve 18 is almost in the full-closed position (e.g., $THR_M = 0.9$) a relatively small change in the commanded position THR_{CMD} of the valve 18 may have a considerable effect on the measured intake manifold pressure--because the air flow through the manifold 16 is almost completely restricted. Accordingly, if the measured position THR_M of the valve 18 approaches the full-closed position ($THR_M = 1$), the scaling factor $(1 - THR_M)^2$ substantially decreases the calculated error P_{ERRO} which provides for a relatively small change in the commanded position THR_{CMD} of the valve 18. Alternately, if the measured position THR_M of the valve 18 approaches the full-open position ($THR_M = 0$), the scaling factor $(1 - THR_M)^2$ decreases the calculated error P_{ERRO} by a relatively small amount which provides for a relatively larger change in the commanded position THR_{CMD} of the valve 18.

[0052] In the substep 114 the value Z is calculated using the following equation: $Z = Z + (Ki * P_{ERRO})$ where Z represents the integrated value of the error P_{ERRO} and Ki represents an integration gain that is preferably greater than zero ($Ki > 0$). In the substep 116, the first target position THR_1 is calculated using the following equation: $THR_1 = Z + (Kp * P_{ERRO})$; where Kp represents a proportional gain that is preferably greater than zero ($Kp > 0$).

[0053] Referring to Figure 2E, the substep 104 after the substep 102 sets a second target position THR_2 equal to a predetermined position THR_P (e.g., $THR_M = 0.7$) of the throttle valve 18. The position THR_P represents a threshold throttle valve position for causing an increase in the exhaust gas temperature of the engine 12. Accordingly, any further throttling of the valve 18 from the position THR_P results in an increase in the exhaust gas temperature. The position THR_P is utilised to preset the position of the throttle valve 18 to provide a faster response time for increasing the exhaust gas temperature.

[0054] In the substep 106, the commanded position THR_{CMD} for the throttle valve 18 is calculated responsive to the first target position THR_1 and the second target position THR_2. Referring to Figure 2G, the substep 106 may include the substeps 118, 120, 122, 124, 126, 128, 130, 132, 134, and 136. In the substep 118, the first target position THR_1 is added to the second target position THR_2 to obtain the commanded position THR_{CMD} of the throttle valve 18.

[0055] The substep 120 determines if the commanded position THR_{CMD} of the valve 18 is less than a minimum throttle valve position THR_{MIN}. The minimum valve position THR_{MIN} is preferably equal to zero representing the full-open position of the valve 18. If the commanded position THR_{CMD} is less than the minimum throttle valve position THR_{MIN}, the substep 122 sets the position THR_{CMD} equal to the position THR_{MIN} before advancing to the substep 124.

[0056] The substep 124 determines if the commanded position THR_{CMD} of the throttle valve 18 is greater than a maximum throttle valve position THR_{MAX}. The position THR_{MAX} is preferably equal to one representing the full-closed position of the valve 18. If the commanded position THR_{CMD} is greater than the maximum throttle valve position THR_{MAX}, the substep 126 sets the position THR_{CMD} equal to the position THR_{MAX} before advancing to the substep 128.

[0057] The substep 128 determines if the measured engine speed N is less than a minimum engine speed N_{MIN} required for proper operation of the engine 12. If the engine speed N is less than the minimum engine speed N_{MIN}, the commanded position THR_{CMD} of the valve 18 is set to the full-open position ($THR_{CMD} = 0$) in substep 130. Accordingly, the method ensures that the speed of the engine 12 is always maintained above the minimum allowable engine speed N_{MIN}.

[0058] The substep 132 determines if the regeneration flag R_{FLAG} is set to a true condition or a false condition. If the regeneration flag R_{FLAG} is set to the true condition (indicating that the filter 48 should be regenerated), the method advances to the step 138 (shown in Figure 2A). If the flag R_{FLAG} is set to a false condition, the substep 134 sets the commanded position THR_{CMD} of the throttle valve 18 to the full-open position ($THR_{CMD} = 0$) and the substep 136 sets the integrated value of P_{ERRO} equal to zero.

[0059] Referring to Figure 2A, the method may further include a step 138 that controls the throttle valve 18 responsive to the commanded position THR_{CMD} to control the exhaust gas temperature of the engine 12.

[0060] The method may further include a step 140 that sets a commanded engine speed N_C to a predetermined speed to further control the exhaust temperature of the engine 12. The predetermined speed may be a slightly increased idle speed between about 700 RPM to 1000 RPM.

[0061] Finally, the method may include a step 142 that injects a second predetermined amount of fuel into one or more of the cylinders 44 of the engine 12 late in a power stroke (i.e., post-injection of fuel) of the one or more cylinders 44, respectively, to further control the exhaust temperature. In particular, the microcontroller 14 may generate a control signal that causes the fuel injector 21 to inject the second predetermined amount of fuel into one of the cylinders 44. The post-injection of fuel may be initiated when the temperature of the exhaust gas in the oxidation catalyst 46 reaches a temperature of 200° C. In response, the exhaust gas temperature within the oxidation catalyst 46 is increased as discussed above.

[0062] From the foregoing description of the inventive method, it should be understood that the commanded position THR_{CMD} of the valve 18 and the commanded engine speed N_C may be utilised to increase the exhaust gas temperature of the engine 12 above 450°C to allow regeneration of the filter 48. Alternately, the commanded position THR_{CMD}, the commanded engine speed N_C, and the post-injection of fuel into one or more cylinders 44 may be utilised to increase the exhaust gas temperature of the engine 12 above 450°C to allow regeneration of the filter 48.

[0063] Referring to Figures 3A-F, the parameters of a diesel engine controlled by the inventive method are illustrated. More specifically, Figures 3A-F illustrate how the inventive method is utilised to control the throttle valve 18 and the engine speed of the engine 12 to increase the exhaust gas temperature above a predetermined temperature (e.g., 450°C to thereby regenerate the filter 48. In the illustrated embodiment, the target engine operational parameter TP corresponds to a target intake manifold pressure P_T. Further, the measured engine operational parameter MP corresponds to a measured intake manifold pressure P_M. Accordingly, the target intake manifold pressure P_T and the measured intake manifold pressure P_M are utilised to control the throttle valve 18.

[0064] Referring to Figures 2A, 3A, and 3D, during the first ten seconds of operation of the engine 12, the speed control flag N_{FLAG} is set to a true condition (indicating idle mode) and the steps 58, 62 maintain the engine speed N at the commanded engine speed N_C equal to 800 RPM. Referring to Figure 3C, during the first ten seconds the exhaust gas temperature T is approximately 150°C which is below the temperature required to initiate regeneration of the filter 48. At time T=10 seconds, the step 66 determines that the regeneration flag R_{FLAG} is set to a true condition (indicating filter 48 should be regenerated). Referring to Figure 3B, the target intake manifold pressure P_T is equal to 35 kilopascals (kPa) and the measured intake manifold pressure is equal to 60 kPa. In response to the large difference between the measured intake manifold pressure P_M and the target intake manifold pressure P_T (i.e., intake manifold pressure error), the steps 68, 98 modify the commanded position THR_{CMD} of throttle valve 18 and the step 138 directs the actuator 20 to begin throttling the throttle valve 18 (as shown in Figure 3A) to lower the pressure P_M towards the pressure P_T.

[0065] Referring to Figures 3B and 3D at time T=15 seconds, in response to the throttling of the throttle valve 18, the measured intake manifold pressure P_M decreases to 55 kPa and the engine speed N falls below the commanded engine speed N_C. In response, the step 68 increases the target intake manifold pressure P_T (over time interval T=10-18 seconds) to prevent further throttling of the valve 18 to thereby increase the engine speed N towards the commanded engine speed N_C. At approximately time T=22 seconds, when the engine speed error N_{ERR} (N_{ERR} = N - N_C) has been reduced sufficiently, the target intake manifold pressure P_T is again gradually reduced (over time interval T=22-38 seconds). Referring to Figure 3C, as a result of the step 138 throttling the throttle valve 18, the engine exhaust temperature T is increased to about 400°C at time T=38 seconds.

[0066] Referring to Figure 3F at time T=38 seconds, the measured air/fuel ratio AF has fallen slightly below the minimum air/fuel ratio AF_{MIN}. In response, the step 68 increases the target intake manifold pressure P_T to ensure that the measured air/fuel ratio AF does not decrease any further.

[0067] Referring to Figure 3D at time T=45 seconds, the step 140 increases the commanded engine speed N_C gradually from 800 RPM to 1000 RPM. Because of the resulting engine speed error N_{ERR} (N_{ERR} = N - N_C) and a small decrease in the measured air/fuel ratio AF (see Figure 3F), the step 68 rapidly increases the target intake manifold pressure P_T. The increase in the pressure P_T allows the step 140 to increase the commanded engine speed N_C up to 1000 RPM without a significant engine speed error N_{ERR} or a significant air/fuel error AF_{ERR} (AF_{ERR} = AF - AF_{MIN}).

[0068] Referring to Figure 3D at time T=55 seconds, once the commanded engine speed N_C has reached a predetermined speed (e.g., 1000 RPM), the step 68 reduces the target intake manifold pressure P_T towards a base intake manifold pressure of 35 kPa. However, the step 68 does not allow the target intake manifold pressure P_T to reach the base intake manifold pressure because doing so would result in the air/fuel ratio AF decreasing below the minimum air/fuel ratio AF_{MIN}. Referring to Figure 3C at time T=55 seconds, the exhaust temperature of the exhaust gas entering filter assembly 24 is about 550°C. Accordingly, the exhaust gas incinerates the carbon particles in the filter 48 and regenerates the filter 48.

[0069] A method for controlling an engine exhaust temperature in accordance with the present invention represents a significant improvement over conventional methods. In particular, the inventive method allows for the regeneration of particulate filters during low engine speeds (e.g., engine speed less than 1000 RPM) and/or low engine load conditions. As a result, the inventive method allows particulate filters to operate more effectively when the vehicle engine is idling or is being operated at relatively low speeds. The invention may further include the automotive vehicle 10 having the engine 12 and the filter assembly 24 controlled using the above-identified inventive method.

Claims

1. A method of controlling an exhaust gas temperature of an internal combustion engine (12) during low engine (12) speeds or low engine load conditions, said

engine having cylinders (44), an intake manifold (16), and a throttle valve (18) disposed within said intake manifold (16), the method comprising the steps of:

calculating a target engine operational parameter responsive to an air/fuel ratio of said engine and an engine speed error of said engine;
calculating a commanded position for said throttle valve (18) responsive to said target engine operational parameter and a measured engine operational parameter; and,
controlling said throttle valve (18) responsive to said commanded position to control said exhaust gas temperature.

2. A method as claimed in Claim 1 , where said target operational parameter comprises a target intake manifold pressure and said measured engine operational parameter comprises a measured intake manifold pressure.

3. A method as claimed in claim 1, wherein said target engine operational parameter comprises a target intake manifold mass air flow and said measured engine operational parameter comprises a measured intake manifold mass air flow.

4. A method as claimed in claim 1, wherein said target engine operational parameter comprises a target air/fuel ratio and said measured engine operational parameter comprises a measured air/fuel ratio.

5. A method as claimed in claim 1, wherein said air/fuel ratio comprises a measured air/fuel ratio in said engine.

6. A method as claimed in claim 1, wherein said air/fuel ratio is calculated responsive to a fuelling level of said engine and a measured mass air flow in said intake manifold.

7. A method as claimed in claim 1, wherein said step of calculating said target engine operational parameter includes the substeps of:

calculating a first target offset responsive to said engine speed error;
calculating a second target offset responsive to said air/fuel ratio;
adding said first target offset to said second target offset to obtain a target reference offset; and,
adding said target reference offset to a predetermined base engine operational parameter to obtain said target engine operational parameter.

8. A method as claimed in claim 1, wherein said step of calculating said commanded position of said throttle valve includes the substeps of:

subtracting said target engine operational parameter from a measured engine operational parameter to obtain an engine operational parameter error;
calculating a first target position responsive to said engine operational parameter error and a measured position of said throttle valve;
setting a second target position equal to a predetermined position; and,
calculating said commanded position of said throttle valve responsive to said first target position and said second target position.

9. A method as claimed in claim 1, further comprising the step of:
setting said commanded engine speed to a predetermined speed to further control said exhaust gas temperature.

10. A method as claimed in claim 1, further comprising the step of:
injecting a predetermined amount of fuel into one of said cylinders late in a power stroke of said cylinder to further control said exhaust gas temperature.

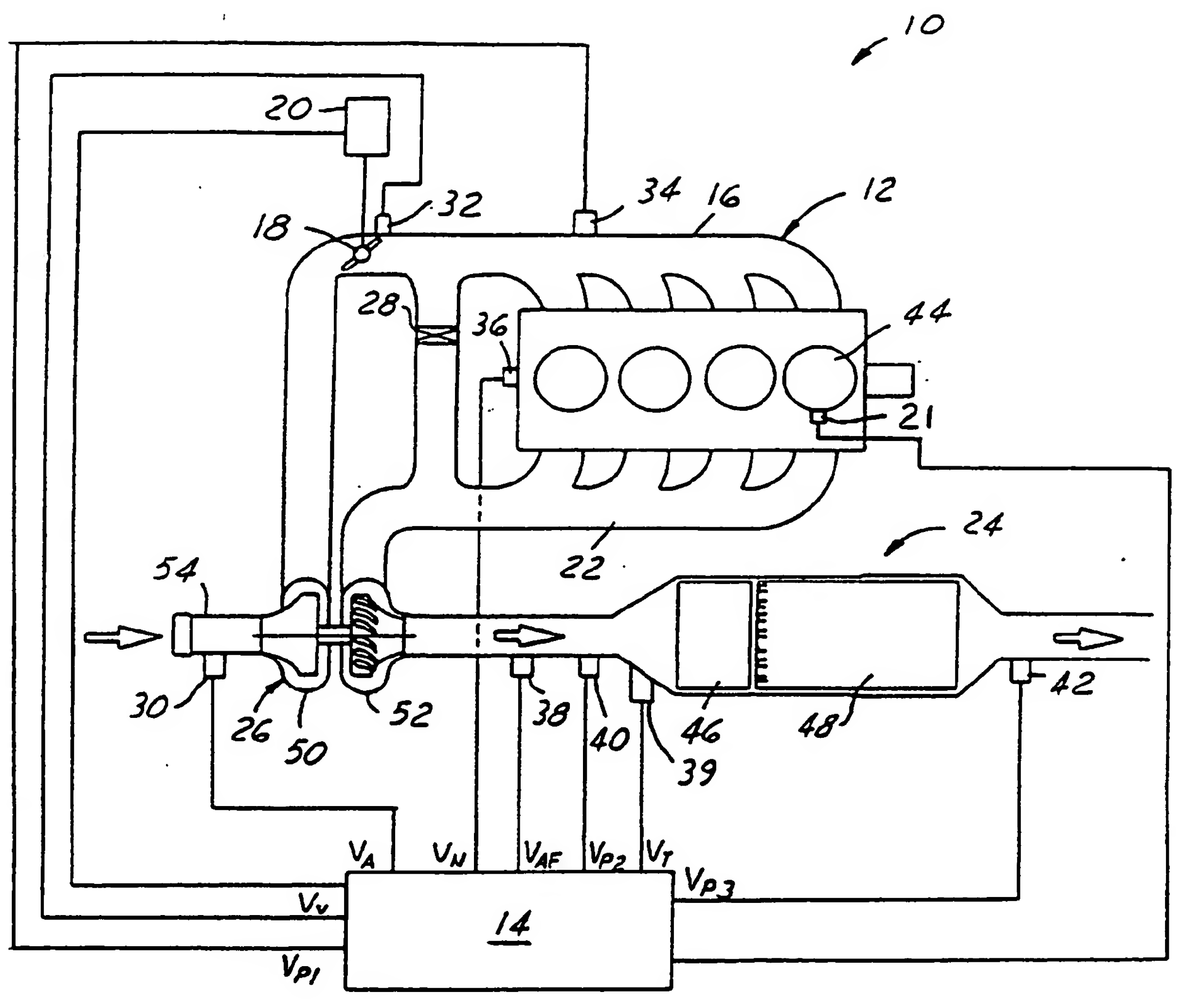

10
20
32
34
16
12
18
28
36
44
21
24
54
22
30
26
50
52
38
40
46
48
42
39
V_A
V_N
V_{AF}
V_{P2}
V_T
V_{P3}
V_V
14
V_{P1}

FIG.1

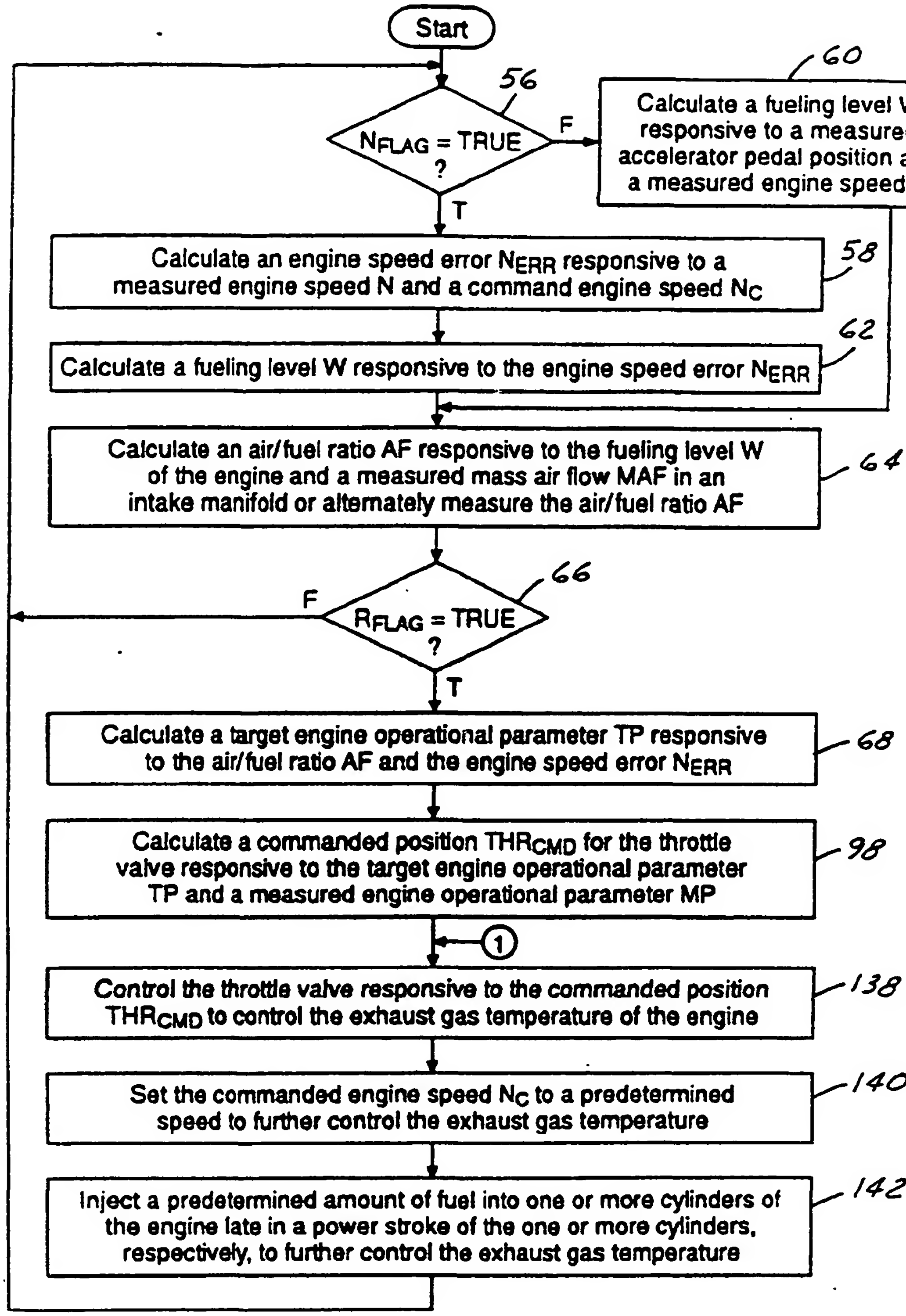

Start
56
NFLAG = TRUE ?
F
T
60
Calculate a fueling level W responsive to a measured accelerator pedal position and a measured engine speed N
Calculate an engine speed error NERR responsive to a measured engine speed N and a command engine speed NC
58
Calculate a fueling level W responsive to the engine speed error NERR
62
Calculate an air/fuel ratio AF responsive to the fueling level W of the engine and a measured mass air flow MAF in an intake manifold or alternately measure the air/fuel ratio AF
64
RFLAG = TRUE ?
66
F
T
Calculate a target engine operational parameter TP responsive to the air/fuel ratio AF and the engine speed error NERR
68
Calculate a commanded position THRCMD for the throttle valve responsive to the target engine operational parameter TP and a measured engine operational parameter MP
98
1
Control the throttle valve responsive to the commanded position THRCMD to control the exhaust gas temperature of the engine
138
Set the commanded engine speed NC to a predetermined speed to further control the exhaust gas temperature
140
Inject a predetermined amount of fuel into one or more cylinders of the engine late in a power stroke of the one or more cylinders, respectively, to further control the exhaust gas temperature
142

FIG. 2A

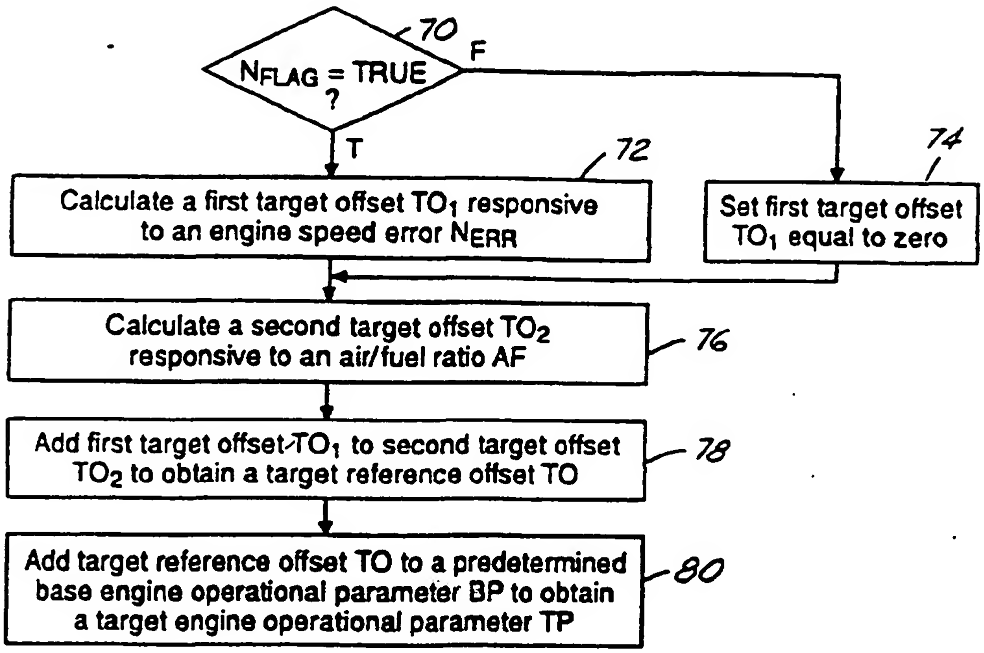


FIG.2B

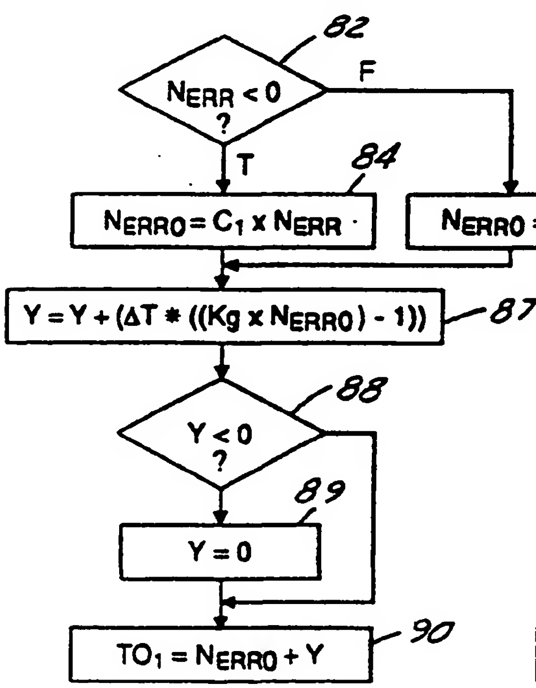


FIG.2C

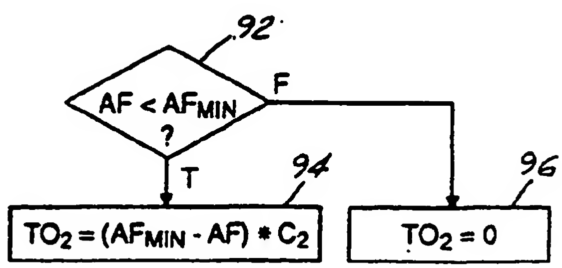


FIG.2D

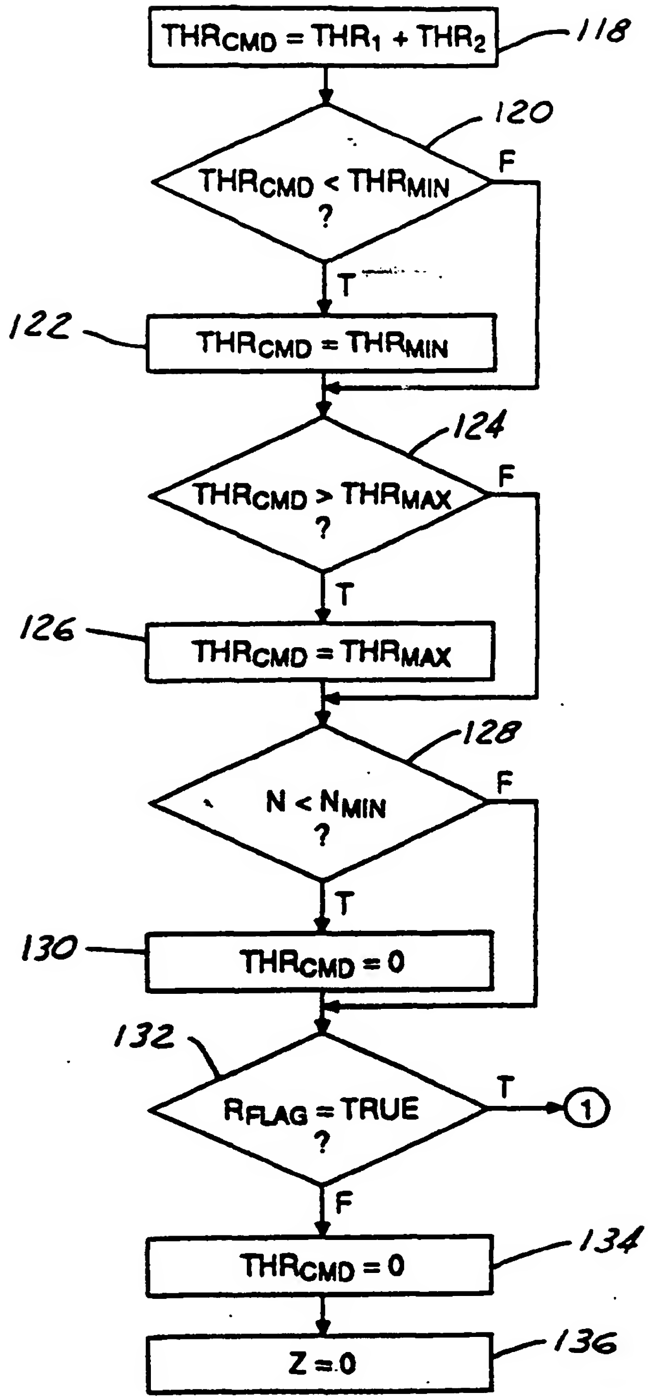
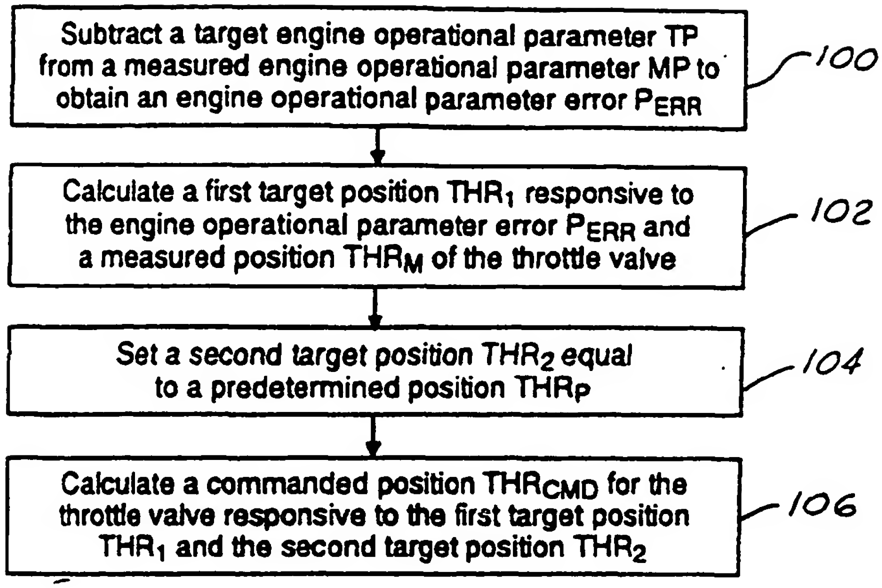
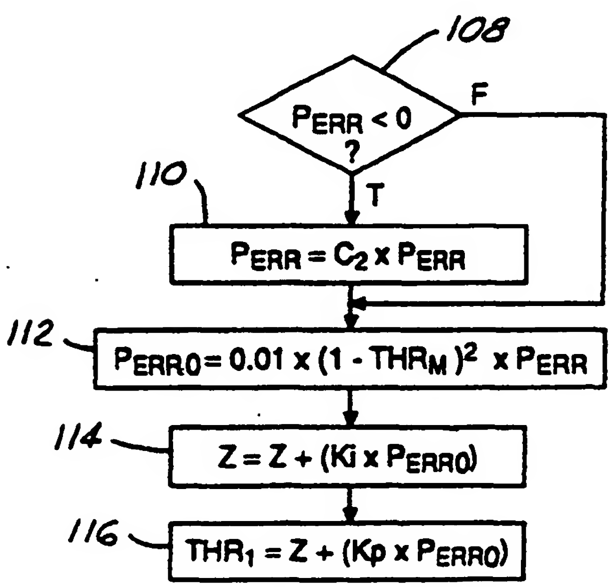

$THR_{CMD} = THR_1 + THR_2$
118
120
$THR_{CMD} < THR_{MIN}$?
F
T
122
$THR_{CMD} = THR_{MIN}$
124
$THR_{CMD} > THR_{MAX}$?
F
T
126
$THR_{CMD} = THR_{MAX}$
128
$N < N_{MIN}$?
F
T
130
$THR_{CMD} = 0$
132
$R_{FLAG} = TRUE$?
T
1
F
134
$THR_{CMD} = 0$
136
Z = 0

FIG.2G



Subtract a target engine operational parameter TP from a measured engine operational parameter MP to obtain an engine operational parameter error P_{ERR}
100
Calculate a first target position THR_1 responsive to the engine operational parameter error P_{ERR} and a measured position THR_M of the throttle valve
102
Set a second target position THR_2 equal to a predetermined position THR_P
104
Calculate a commanded position THR_{CMD} for the throttle valve responsive to the first target position THR_1 and the second target position THR_2
106

FIG.2E



108
$P_{ERR} < 0$?
F
T
110
$P_{ERR} = C_2 \times P_{ERR}$
112
$P_{ERR0} = 0.01 \times (1 - THR_M)^2 \times P_{ERR}$
114
$Z = Z + (Ki \times P_{ERR0})$
116
$THR_1 = Z + (Kp \times P_{ERR0})$

FIG.2F

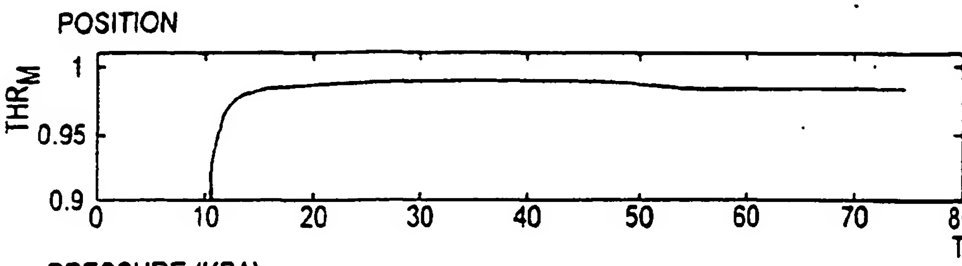


FIG. 3A

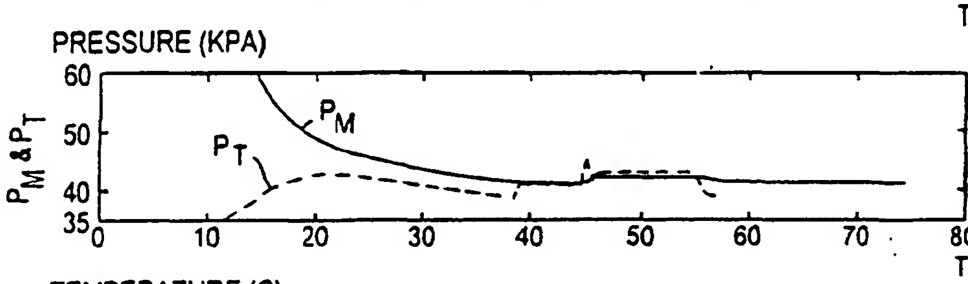


FIG. 3B

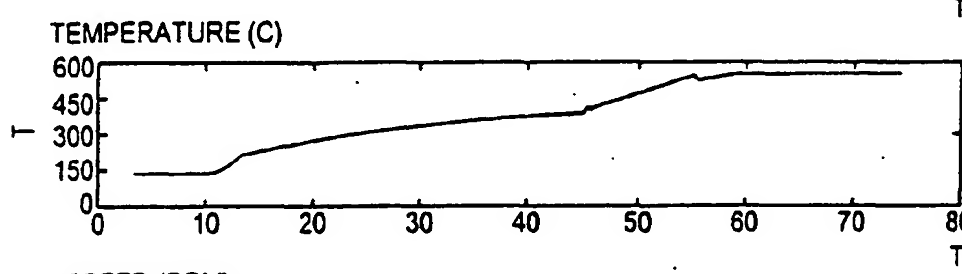


FIG. 3C

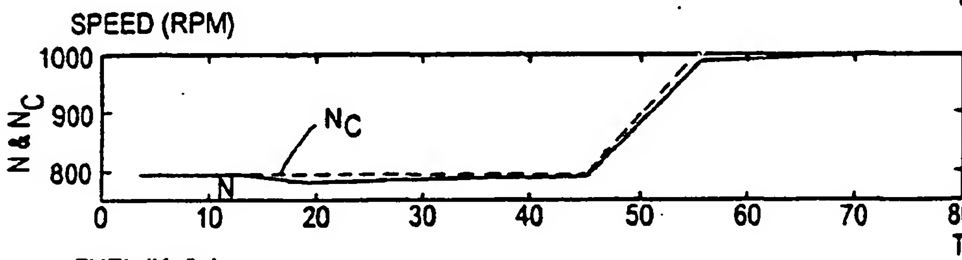


FIG. 3D

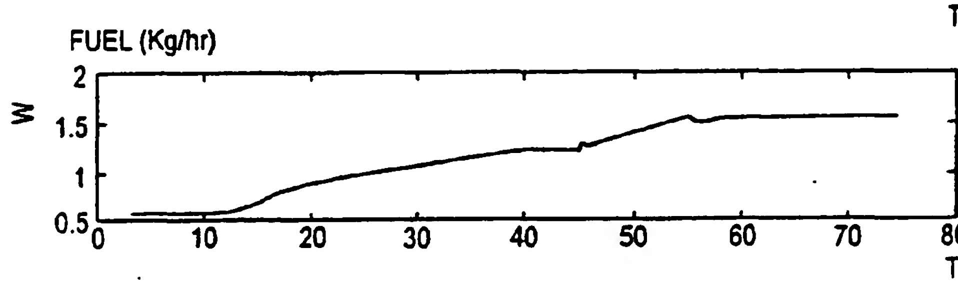


FIG. 3E

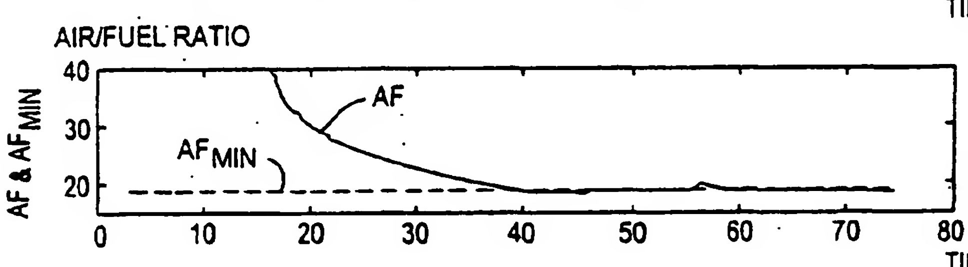


FIG. 3F

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(54) Method for controlling an exhaust gas temperature of an engine

(57) A method of controlling an exhaust gas temperature of an internal combustion engine 12 during low engine speeds and low engine load conditions is provided. The method includes the step 68 of calculating a target engine operational parameter responsive to an air/fuel ratio of the engine 12 and an engine speed error. The target engine operational parameter is one the following parameters: a target intake manifold pressure, a target intake manifold mass air flow, or a target air/fuel ratio. The method further includes the step 98 of calculating a commanded position for a throttle valve 18 disposed in an intake manifold 16 of the engine 12. The commanded position is calculated responsive to the target engine operational parameter and a measured engine operational parameter. The measured engine operational parameter is one of the following parameters: a measured intake manifold pressure, a measured intake manifold mass air flow, or a measured air/fuel ratio. The method further includes the step 138 of controlling the throttle valve 18 responsive to the commanded position to control the exhaust gas temperature of the engine 12. The method further includes the step 140 of setting a commanded engine speed to a predetermined speed to further control the exhaust gas temperature. Finally, the method includes the step 142 of injecting a predetermined amount of fuel into one of the cylinders 44 of the engine 12 late in a power stroke of the one or more cylinders 44 to further control the exhaust gas temperature.

EP 1 146 216 A3

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EUROPEAN SEARCH REPORT

Application Number
EP 01 30 2321

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	16 March 2004	Lapeyronnie, P

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Application Number
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